Table of Contents

Section			Page
6.1	GENERAL		6-1
6.2	GUIDANCE AND REFERENCES		6-2
	6.2.1	General References	6-2
	6.2.2	Geology, Landslides and Field Procedures	6-2
	6.2.3	Structures and Foundations	6-3
	6.2.4	Material and Pavement Design.	6-4
	6.2.5	Subsurface Drainage	6-4
	6.2.6	Computer Programs	6-5
6.3	INVESTIGATION PROCESS		6-7
	6.3.1	Geotechnical Equipment	6-9
	6.3.2	Planning Geotechnical Investigations	6-10
	6.3.3	Drilling and Sampling	6-15
	6.3.4	Geophysical and In-Situ Tests	6-24
	6.3.5	Laboratory Tests	6-36
6.4	GEOTECHNICAL ANALYSIS		6-40
	6.4.1	Roadway Soils	6-40
	6.4.2	Structure Foundations	6-58
	6.4.3	Retaining Walls	6-71
	6.4.4	Pavement Design	6-73
	6.4.4.1	New and Reconstructed Pavement Design	6-77
	6.4.4.2	Pavement Overlay Design	6-93
	6.4.4.3	Pavement Rehabilitation Design Other Than Overlay	6-94
	6.4.5	Material Sources	6-95
	6.4.6	Landslide Analysis	6-99
	6.4.7	Subsurface Drainage	6-100
6.5	APPROVALS (RESERVED)		6-116
6.6	GEOTECHNICAL REPORTS		6-117
	6.6.1	Report Structure and Outline	6-117
	6.6.2	Checklists	6-118
	6.6.3	Standard Forms	6-119
6.7	DIVISION PROCEDURES		6-120

List of Exhibits

Exhibit		Page
Exhibit 6.3-A	POSSIBLE SOURCES FOR SITE-SPECIFIC INFORMATION	6-7
Exhibit 6.3-B	GENERAL INVESTIGATION EQUIPMENT REQUIREMENTS	6-11
Exhibit 6.3-C	SOURCES OF REGIONAL GEOTECHNICAL INFORMATION	6-12
Exhibit 6.3-D	USE OF TRENCHING AND TEST PITS	6-13
Exhibit 6.3-E	GUIDELINES FOR GEOTECHNICAL DRILLINING INVESTIGATIONS*	6-14
Exhibit 6.3-F	TEST BORINGS — TYPES AND APPLICATION	6-15
Exhibit 6.3-G	SAMPLING GUIDELINES	6-16
Exhibit 6.3-H	SAMPLE BORING LOG	6-19
Exhibit 6.3-I	BORING LOG TERMINOLOGY	6-20
Exhibit 6.3-J	BORING LOG TERMINOLOGY (Soil Description)	6-21
Exhibit 6.3-K	FIELD CLASSIFICATIONS FOR SOIL AND ROCK	6-22
Exhibit 6.3-L	GUIDELINES FOR USING GEOPHYSICAL METHODS	6-25
Exhibit 6.3-M	ESTIMATING RIPPABILLITY OF MATERIALS FROM SEISMIC WAVE VELOCITIES*	6-26
Exhibit 6.3-N	SEISMOGRAPH DATA SHEET	6-28
Exhibit 6.3-O	RESISTIVITY DATA SHEET	6-30
Exhibit 6.3-P	COMMON PROCEDURAL ERRORS USING STANDARD PENETRATION TEST	6-33
Exhibit 6.3-Q	EMPIRICAL VALUES, RELATIVE DENSITY AND MASS DENSITY OF GRANULAR SOILS(1)	6-33
Exhibit 6.3-R	SAMPLE CONE PENETROMETER TEST (CPT) DATA FORM (RESERVED)	6-35
Exhibit 6.3-S	BORE HOLE SHEAR TEST	6-37
Exhibit 6.3-T	INCLINOMETER DATA	6-38
Exhibit 6.3-U	GUIDELINES FOR SELECTION OF LABORATORY TESTS	6-39

List of Exhibits
(Continued)

Exhibit		Page
Exhibit 6.4-A	SHRINK/SWELL FACTORS FOR COMMON MATERIALS*	6-48
Exhibit 6.4-B	SAMPLE OF A SOILS AND FOUNDATION PLAN AND PROFILE SHEET	6-53
Exhibit 6.4-C	ROCK SLOPE DESIGN CRITERIA*	6-56
Exhibit 6.4-D	ROADWAY SOILS ANALYSIS FACTORS	6-59
Exhibit 6.4-E	PRELIMINARY FOUNDATION TYPE SELECTION	6-60
Exhibit 6.4-F	REGIONAL FACTOR GUIDELINES FOR PAVEMENT	6-79
Exhibit 6.4-G	SOIL SUPPORT CORRELATIONS	6-84
Exhibit 6.4-H	DESIGN CHART FOR FLEXIBLE – P_t = 2.0	6-86
Exhibit 6.4-I	DESIGN CHART FOR FLEXIBLE PAVEMENTS – P_t = 2.5	6-88
Exhibit 6.4-J	TYPICAL UNDERDRAIN INSTALLATION FOR ROADBEDS AND DITCHES	6-105
Exhibit 6.4-K	TYPICAL UNDERDRAIN INSTALLATION IN EMBANKMENT AREAS	6-107
Exhibit 6.4-L	TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED	6-109
Exhibit 6.4-M	TYPICAL UNDERDRAIN INSTALLATION FOR SPRING AREAS	6-111
Exhibit 6.4-N	TYPICAL UNDERDRAIN INSTALLATION FOR BACKSLOPE	6-113

List of Forms

Form		Page
Form 6.3-A	PRELIMINARY GEOTECHNICAL INVESTIGATION FORM	6-8
Form 6.3-B	PRELIMINARY BORING AND TESTING PLAN	6-17
Form 6.3-C	BORING LOG	6-18
Form 6.4-A	SITE INVESTIGATION CHECKLIST	6-42
Form 6.4-B	SAMPLE OF ROADWAY CUT AND EMBANKMENT CHECKLIST	6-43
Form 6.4-C	FIELD MAPPING – ROCK STRUCTURES*	6-45
Form 6.4-D	SAMPLE OF SUMMARY OF SOIL SURVEY	6-46
Form 6.4-E	SUMMARY OF WATER PROBLEM AREAS	6-47
Form 6.4-F	SAMPLE OF INTERPRETED DESIGN SOIL PROFILE	6-52
Form 6.4-G	SAMPLE OF GENERAL REPORT CHECKLIST	6-54
Form 6.4-H	SAMPLE OF SITE INVESTIGATION CHECKLIST	6-55
Form 6.4-I	ALLOWABLE BEARING PRESSURE FOR SPREAD FOOTINGS	6-62
Form 6.4-J	ALLOWABLE PILE CAPACITY CURVE	6-64
Form 6.4-K	SAMPLE OF SPREAD FOOTING CHECKLIST	6-67
Form 6.4-L	SAMPLE OF PILES CHECKLIST	6-68
Form 6.4-M	SAMPLE OF DRILLED SHAFT CHECKLIST	6-70
Form 6.4-N	SAMPLE OF RETAINING WALL CHECKLIST	6-74
Form 6.4-O	SAMPLE OF PAVEMENT DESIGN CHECKLIST	6-76
Form 6.4-P	PAVEMENT BORE LOG	6-80
Form 6.4-Q	SAMPLE OF ASPHALT CONCRETE PAVEMENT CONDITION SURVEY	6-81
Form 6.4-R	PORTLAND CEMENT CONCRETE PAVEMENT CONDITION SURVEY*	6-83
Form 6.4-S	PAVEMENT STRUCTURE LAYER THICKNESS WORKSHEET	6-90

List of Forms
(Continued)

Form		Page
Form 6.4-T	SAMPLE OF MATERIAL SOURCE INVESTIGATION CHECKLIST	6-97
Form 6.4-U	SAMPLE OF LANDSLIDE CORRECTION CHECKLIST	6-101

CHAPTER 6

GEOTECHNICAL

6.1 GENERAL

This Chapter provides guidance for all geotechnical investigations, analyses and reports produced by the Federal Lands Highway Divisions. Although greatly advanced in recent years, the state-of-the-art of the geotechnical engineering field is still largely dependent upon engineering judgment to provide the most efficient and economical investigations. Dealing with the variability of projects, terrains, climates and client agency constraints requires flexibility and resourcefulness.

Although primarily intended for use by a geotechnical engineer/geologist, the information contained herein can be used by designers and others during the design process. Geotechnical responsibilities include conducting investigations, performing analyses and providing recommendations for the following:

- geological and geotechnical reconnaissance,
- cut and fill slopes,
- foundations,
- landslides,
- material sources,
- retaining walls,
- subsurface drainage, and
- pavements.

Each of these areas are addressed individually, providing guidelines, direction and references for more specific and detailed information.

6.2 GUIDANCE AND REFERENCES

The publications listed in this Section provided much of the fundamental source information used in the development of this Chapter. While this list is not all-inclusive, the publications listed will provide additional information to supplement this *Manual*.

6.2.1 General References

1. Bowles, *Foundation Analysis and Design*, 4th ed., McGraw-Hill Book Company, 1988.

2. Peck, Hanson, and Thornburn, *Foundation Engineering*, John Wiley and Sons, Inc., 1974.

3. Terzaghi and Peck, *Soil Mechanics in Engineering Practice*, John Wiley and Sons, Inc., 1967.

4. Wintercorn, *Foundation Engineering Handbook*, 2nd ed., Van Nostrand Reinhold Company, 1991.

5. *Canadian Foundation Engineering Manual*, 3rd ed., Canadian Geotechnical Society, 1992.

6. *Geotechnical Engineering Notebook*, DOT, FHWA, Office of Engineering, Bridge Division.

7. Geotextile Engineering Manual, DOT, FHWA, 1984.

8. Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction, *NAVFAC Design Manual* 7.3, Department of the Navy, April 1983.

9. Soil Mechanics, *NAVFAC Design Manual* 7.1, Department of the Navy, September 1986.

6.2.2 Geology, Landslides and Field Procedures

1. Acker, *Basic Procedures for Soil Sampling and Core Drilling*, Acker Drill Co., Inc., 1974.

2. Beck, *Physical Principles of Exploration Methods*, New York, John Wiley and Sons, Inc., 1982.

3. Hamblin and Howard, *Physical Geology Laboratory Manual*, Minneapolis, Burgess Publishing Co., 1975.

4. Hunt, *Geotechnical Engineering Investigation Manual*, New York, McGraw-Hill Book Co., 1984.

5. Pitts, *A Manual of Geology for Civil Engineers*, Salt Lake City, John Wiley and Sons, Inc., 1984.

6. *Manual on Subsurface Investigations*, AASHTO, 1988.

7. *Driller's Safety Manual*, US Department of the Interior, Bureau of Reclamation, 1973.

8. Geotechnical Instrumentation, *FHWA Workshop Manual*, DOT, FHWA.

9. *The Cone Penetrometer Test*, FHWA-SA-91-043, DOT, FHWA, 1992.

10. *The Flat Dilatometer Test*, FHWA-SA-91-044M, DOT, FHWA, 1992.

11. *Advanced Technology for Soil Slope Stability*, FHWA-SA-94-005, DOT, FHWA, 1994.

12. *Handbook of Engineering Geophysics* (Volume 1, Seismic, 1984 and Volume 2, Electrical Resistivity, 1980), Minneapolis, Bison Instruments, Inc.

13. *The Pressuremeter Test for Highway Application*, FHWA-IP-89-008, DOT, FHWA, 1989.

14. *Landslides Investigation and Mitigation*, Transportation Research Board, National Academy of Sciences, Washington, DC, 1995.

15. *Rock Slopes: Design, Excavation, Stabilization*, FHWA-TS-89-045, DOT, FHWA, 1989.

16. *Rock Blasting and Overbreak Control*, FHWA-HI-92-001, DOT, FHWA, 1991.

17. Duncliff, *Geotechnical Instrumentation for Monitoring Field Performance*, John Wiley & Sons, Inc., 1988.

6.2.3 Structures and Foundations

1. Poulos and Davis, *Pile Foundation Analysis and Design*, 1980.

2. *Drilled Shafts: Construction Procedures and Design Methods*, DOT, FHWA, 1988.

3. *Handbook on Design of Piles and Drilled Shafts Under Lateral Load*, FHWA-IP-84-011, DOT, FHWA, 1984.

4. *Behavior of Piles and Pile Groups Under Lateral Load*, FHWA-RD-85-106, DOT, FHWA, 1986.

5. *LFRD Bridge Design Specifications*, AASHTO, 1994.

6. Reeves, *Applications of Walls to Landslide Control Problems*, American Society of Civil Engineers, 1982.

7. *Spread Footings for Highway Bridges*, FHWA-RD-86-185, DOT, FHWA, 1987.

8. *Manual on Foundation Investigation*, AASHTO, 1978.

9. AASHTO-AGC-ARTBA Taskforce Report, *In-Situ Improvement Techniques*, 1990.

10. Foundation and Earth Structures, *NAVFAC Design Manual* 7.2; NAVFAC DM-7.2, Department of the Navy, 1982.

11. *Permanent Ground Anchors*, FHWA-DP-68-1R, DOT, FHWA, 1984.

12. *Manual on Design and Construction of Driven Pile Foundations*, FHWA DP-66-1, DOT, FHWA, Office of Engineering, Bridge Division, 1986.

13. *Retaining Wall Design Guide*,2nd ed. (FHWA-FLP-94-006), US Department of Agriculture, Forest Service, September 1994.

14. *Soils and Foundation Workshop Manual*, DOT, FHWA, Office of Engineering, Bridge Division, 1993.

6.2.4 Material and Pavement Design.

1. *Techniques for Pavement Rehabilitation, A Training Course*, 3rd Revision, ERES Consultants, Inc., 1987.

2. *Pavement Design Principles and Practices, A Training Course*, ERES Consultants, Inc., 1987.

3. Krebs and Walker, *Highway Materials*, McGraw-Hill Book Company, 1971.

4. Yoder and Witczak, *Principles of Pavement Design*, 2nd ed., John Wiley and Sons, Inc., 1975.

5. *AASHTO Pavement Overlay Design*, FHWA-HI-94-048, DOT, FHWA, 1994.

6. *Distress Identification Manual for the Long-Term Pavement Performance Projects*, SHRP-P-338, SHRP, 1993.

7. *Guide for Design of Pavement Structures*, AASHTO, 1993.

8. *Pavement Rehabilitation Manual*, DOT, FHWA, Office of Engineering, Pavement Division, 1990.

9. *Soils Manual for the Design of Asphalt Pavement Structures*, The Asphalt Institute, 1986.

10. *Thickness Design - Asphalt Pavements for Highways and Streets*, The Asphalt Institute, 1991.

11. *Pavement Notebook for FHWA Engineers*, Office of Engineering, Pavement Division.

6.2.5 Subsurface Drainage

1. *Geotextile Design and Construction Guidelines*, FHWA-HI-95-038, DOT, FHWA, 1995.

2. Drainage of Asphalt Pavement Structures, *The Asphalt Institute Manual*, Series No. 15, September 1984 ed.

3. *Geocomposite Drains*, Report No. FHWA/RD-86/171, DOT, FHWA, October 1986.

4. *Geotechnical Fabrics*, Report No. FHWA/RD-80/021, DOT, FHWA, 1980.

5. *Highway Subdrainage Design*, Report No. FHWA-TS-80-224, DOT, FHWA, 1980.

6. *Improving Subdrainage and Shoulders of Existing Pavements*, Report No. FHWA/RD-81/078, DOT, FHWA, January 1982.

7. *Underground Disposal of Storm Water Runoff*, Report No. FHWA-TS-80-218, DOT, FHWA, March 1980.

6.2.6 Computer Programs

The following is a listing of computer programs that are available and may be used when appropriate:

1. **Foundations**. The following computer programs are used for analyzing soils for foundations:

   - GRL WEAP 1.994-1 - Wave Equation Analysis of Piles,
   - NAVPILE - Nevada Pile Analysis (Static),
   - COM 624 P Version 2 - Lateral Load Analysis of Driven and Non-Driven Piles,
   - SPILE - Ultimate Static Capacity for Driven Piles, and
   - CBEAR - Bearing Capacity Analysis for Shallow Foundations.

2. **Pavement Design**. The following applies to pavement design:

   - DARWIN - Pavement Design Analysis and Rehabilitation for Windows, and
   - DAMA - Pavement Structural Analysis Using Multi-Layer Elastic Theory.

3. **Slope Stability**. Computer programs that investigate slope stability include the following:

   - LEASE I - Limiting Equilibrium Analysis in Soil Engineering,
   - STABL4 - Slope Stability Analysis,
   - SLOPIN - Calcomp Plot of Inclinometer Data,
   - INCLIN - Print Plot of Inclinometer Data,
   - XSTABL - Slope Stability Analysis,
   - DIGIPRO - Data Reduction and Graphing Software for Inclinometers, and
   - EMBANK - One Dimensional Consolidation due to Embankment Loads.

4. **Geophysical Programs**. The following computer programs analyze seismic stability in soils:

- SEISMIC12 - Channel Refraction Seismic Test Data Analysis,
- RESIST - Resistivity Data Analysis, and
- SEISREFA - Seismic Refraction Analysis.

6.3 INVESTIGATION PROCESS

The primary purpose of a geotechnical investigation is to provide design engineers with a knowledge of the subsurface conditions at a specific project site. The investigation should also provide the construction project engineers and contractors with information concerning the materials and conditions that may be encountered in the field.

The scope and cost of a geotechnical investigation should be adjusted to the size and complexity of the proposed project. The potential for catastrophic failure and/or failure consequences must be evaluated when establishing the scope of the investigation.

In all geotechnical investigations, the safety of the field crew and the traveling public must be of high priority. The nature of the equipment used and climatic conditions often present potential hazards that must be evaluated on an individual basis. It is the responsibility of the geotechnical engineer/geologist, as well as field crew members to adjust the investigation program and/or provide equipment, training and other means to provide safe working conditions. Field crews should be aware of and use traffic safety control plans based upon *MUTCD* requirements.

Geotechnical investigations should not be attempted until certain project-specific information has been obtained. Exhibit 6.3-A identifies typical project requirements and suggests where the necessary information on specific subjects may be obtained. Form 6.3-A is used to gather and document this preliminary information.

Project Specifics	Information Sources
Type of proposed project. Proposed project termini. Funds available. Schedule requirements. Items requiring investigation. Local authorities to contact. Location and type of utilities present.	Planning and Coordination or Project Development Unit
Scope of investigation desired. Availability of equipment.	Geotechnical Engineer
Location of structures.	Structures/Bridge Unit
Site maps and field reference systems.	Location and/or Survey Unit
Specific site restriction such as water quality, environmental considerations, or client agency considerations.	Environmental Unit
Right-of-entry (access) restrictions.	Applicable property owners.

Exhibit 6.3-A POSSIBLE SOURCES FOR SITE-SPECIFIC INFORMATION

Preliminary Information for Geotechnical Investigations

Project: ______________________________ Date: ______________________________

Account Number: ______________________________ Estimated quantity needed: ______________________________

Funding: ______________________________ Information needed by: ______________________________

Type of Investigation? Structure Foundation Roadway Slope Analysis Materials Source Landslide Other _________

Report Type? Preliminary Final Informal Formal

Site Specific Information

Location: ______________________________

Termini: ______________________________ To: ______________________________

Field Reference Available (stakes, MP, etc.): ______________________________

Terrain/Access? Easy Moderate Difficult Very Difficult

Utilities? Water Electric Telephone Unknown

Local Contacts:

Agency Name: ______________________________ Property Owner: ______________________________

Address: ______________________________ Address: ______________________________

Telephone: ______________________________ Telephone: ______________________________

Additional Information Needed By Geotechnical

Mapping? Not Available Availability Date: ______________________________

Structure Foundation Projects

Structure Type: ______________________________ Bridge Spans (No. & Length) ______________________________

Max. Wall Height: __________________ Max. Loads Expected: ______________________________

Availability of Preliminary Plans: ______________________________

Restrictions: ______________________________

Comments: ______________________________

Roadway Projects

Type? Overlay Widening Reconst. New Alignment Other

Pavement Surface Type: ______________________________

Traffic Data Availability: Where? __________________ When? __________________

Restrictions: ______________________________

Comments: ______________________________

Material Source Projects

Use of Material? A.C. Pavement Base Borrow Other _____________

Amount Needed: _______ _____ _____ ______
(m^3) (ft^3)

Suggested Source: ______________________________

Previous Use: ______________________________

Slope/Landslide Projects:

History/Maint. Problems: ______________________________

Estimated Max. Movement Per Year: ______________________________

Previous Correction Attempts: ______________________________

Initial Correction Concepts: ______________________________

Estimated Number of Holes:

Depth: ______________________________ Backhoe or Dozer work required? ______________________________

Is Water Available? ______________________________ How Far? ______________________________

Estimated Conditions: ______________________________

Form 6.3-A PRELIMINARY GEOTECHNICAL INVESTIGATION FORM

Special situations occasionally require in-situ testing or instrumentation to obtain accurate information for both design and construction. These tests and instrumentation may be highly specialized and may require specialized assistance. The following are typical reasons for specialized instrumentation:

- construction control (i.e., both during design and/or construction);
- safety;
- verifying design assumptions;
- verifying new construction techniques;
- verifying long-term satisfactory performance;
- verifying contractor compliance with specifications;
- advancing the state-of-the-art; and
- legal reasons.

6.3.1 Geotechnical Equipment

Sometimes to perform geotechnical investigations, specialized subsurface investigation equipment is required. In cases of sporadic use or when highly trained technicians must be assigned exclusively to operate equipment, the Geotechnical Unit may prefer to use consultants and/or contractors to provide these services in lieu of actually purchasing and maintaining this type of equipment. Below are typical sources for technical assistance to obtain equipment or expertise:

- other FLH offices,
- FHWA research and implementation units,
- local government agencies,
- other Federal government agencies,
- universities,
- private consultants, and
- equipment manufacturers.

Each Geotechnical Unit should maintain access to the latest equipment and technology so it can perform efficient and effective investigations. This policy also provides FHWA the opportunity to implement and experiment with new technology, equipment and ideas. Equipment can be grouped into three major categories:

- drill equipment and sampling tools,
- geophysical and in-situ testing equipment, and
- pavement evaluation equipment.

In addition to these major areas, incidental hand tools are required for the generalized reconnaissance type of investigations usually performed by an engineer or geologist. This equipment consists of, at a minimum:

- a Brunton compass,
- survey transit,
- cloth tape,

- hand level,
- rock hammer,
- hand augers,
- test pit excavation equipment, and
- record keeping notebooks.

Minimum drill equipment should consist of a power auger drill rig capable of advancing an 200-mm (8-in) hollow stem auger to 35 m (115 ft) in very stiff clays or dense sand and gravel. The drill should be capable of traversing soft ground, moderately steep slopes and rough terrain. The drill should also have capabilities for obtaining at least 45 m (148 ft) of "N" size or larger rock cores. Soil testing and sampling capabilities should consist of at least the Standard Penetration Test AASHTO T 206-87(2000) and the Thin Walled Tube Sample AASHTO T 207-96(2000). In addition to the large drilling equipment, a portable drill capable of drilling at least "B" size cores a minimum of 15 m (50 ft) is desirable. Hunt's *Geotechnical Engineering Investigation Manual* provides an excellent source of detailed information on investigation equipment requirements.

The geophysical equipment should consist of a portable, single channel seismic unit and a resistivity unit. In addition, a multi-channel seismic unit with enhancement capability is desirable. Beck's *Physical Principles of Exploration Methods* and the manufacturer's literature provide the best source of geophysical equipment information.

Minimum in-situ test equipment should include a cone penetrometer, a vane shear and in-place density equipment (e.g., sand cone, nuclear gauge). Project site instrumentation (e.g., inclinometer, piezometer, strain gage readout devices) should also be available. A detailed instrumentation equipment listing is available in the *Geotechnical Instrumentation for Monitoring Field Performance* by Dunncliff.

Available pavement evaluation equipment should consist of a calibrated distance measuring device, pavement deflection equipment, roughness measurement and pavement core drill. In addition, access and familiarity with skid testing devices, photo logging and videotape equipment is desirable.

Exhibit 6.3-B provides guidelines for the type of equipment and the frequency of use that is typical for different types of geotechnical investigations.

6.3.2 Planning Geotechnical Investigations

After the project has been initiated, the first phase of any geotechnical investigation should consist of a desk review of available geotechnical information and project specific requirements and information. This information is vital to planning an efficient, cost-effective field investigation. The information is used to do the following:

- determine the nature and scope of the geotechnical field investigation;
- select proper field equipment;
- estimate manpower, time and total costs;
- select field reference system for geotechnical reports; and
- determine site conditions that may restrict or limit the investigation.

Type of Investigation	Use by Equipment Type									
	Hollow Stem Auger Drill	Large Core Drill	Small Core Drill	Seismic	Resistivity	Roughness and Deflection	Water Supply Equipment	In-Situ Monitors	In-Situ Monitors	Backhoe
Roadway Soils	1	4	4	2	3	3	4	3	4	1
Foundations	1	1	2	2	2	4	2	2	2	4
Existing Pavement Evaluations	4	2	1	4	4	1	1	4	4	4
Material Sources	1	1	2	2	2	4	1	4	3	1
Landslides	1	3	3	2	2	4	4	1	1	4
Cutslopes	2	2	2	2	3	4	2	3	2	2

Use Code:

1 = Frequently 3 = Seldom
2 = Occasional 4 = Usually Inappropriate

Exhibit 6.3-B GENERAL INVESTIGATION EQUIPMENT REQUIREMENTS

The wide range of geographical areas where projects may be located requires access to geotechnical information from a variety of sources. Exhibit 6.3-C provides an initial listing of potential sources and a brief description of information available. Each geotechnical unit should supplement the sources listed in Exhibit 6.3-C by establishing and maintaining a file of commonly used regional information.

In addition, the following should be available from the local and/or in-house resource center:

- aerial photographs,
- previous geotechnical reports,
- survey notes, and
- as-built plans.

After this information is obtained and studied, a preliminary boring plan should be developed. This boring plan should contain information on the following:

- type, number and location of proposed test holes;
- estimated depth, type of testing and sampling interval for each hole;
- type and location of utilities;
- list of local contacts for right-of-access and for utilities;
- arrangements for traffic control (e.g., flagmen, signing);
- source of drilling water; and
- instructions for communications, sample handling.

Source	Type of Information	Description
USGS *Index of Publications* Superintendent of Documents US Government Printing Office Washington, DC 20402	water supply papers bulletins professional papers circulars annual reports monographs	General physical geology emphasizing all aspects of earth sciences, including mineral and petroleum resources, hydrology and seismicity, and groundwater resources.
USDOI Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092	index maps quadrangle maps topographic maps	Maps of each State showing coverage and sources of published geological maps. Maps that support the older geological folios including aerial and bedrock maps. Contour maps for all States.
Geological Society of America P. O. Box 9140 3300 Penrose Place Boulder, CO 80302	monthly bulletins special papers memoirs geological maps	Specialized geological subjects and intensive investigations of local geology. Maps of glacial deposits and Pleistocene Aeolian deposits.
USDA Soil Conservation Service *List of Published Soil Surveys* Washington, DC	Soil Maps and Reports	Surveys of surface soils described in agriculture terms, physical geology summarized, and excellent for highway or airfield investigations.
State Geological Surveys/ Geologist Offices	Geological Maps and Reports	Maps/reports covering specific areas or features in the publications of the State geologist.

Exhibit 6.3-C SOURCES OF REGIONAL GEOTECHNICAL INFORMATION

Exhibits 6.3-D and 6.3-E may be used as guidelines for development of an investigation plan. An on-site visit is desirable and often required as part of the development of a detailed investigation plan before field crews begin work at the project site.

Exploration Method	General Use	Capabilities	Limitations
Test Pits/ Shafts (Hand-Excavated).	Bulk sampling, in-situ testing, visual inspection.	Provides data in inaccessible areas, less mechanical disturbance of surrounding ground.	Expensive, time-consuming, limited to depths above groundwater level.
Test Pits/Trenches (Backhoe Excavated).	Bulk sampling in-situ testing, visual inspection, excavation rates, depth of bedrock and groundwater.	Fast, economical, generally less than 3 m (10 ft) deep, can be up to 6 m (20 ft) deep.	Equipment access, generally limited to depths above groundwater level, limited undisturbed sampling.
Drilled Shafts	Pre-excavation for piles and shafts, landslide investigations and drainage wells.	Fast, more economical than hand excavated, minimum 750 mm (30 in) diameter maximum 2 m (6.5 ft) diameter	Equipment access, difficult to obtain undisturbed samples casing may obscure visual inspection, and costly mobilization.
Dozer Cuts	Bedrock characteristics, depth of bedrock and groundwater level, rippability, increase depth capability of backhoes, level area for other exploration equipment.	Relatively low cost, exposures for geologic mapping.	Exploration limited to depth above groundwater level.

Exhibit 6.3-D USE OF TRENCHING AND TEST PITS

Type of Investigation	Number of Borings	Depth of Borings
Structure Foundations	Min. 1 boring per substructure unit.	**Continue borings**: 1. Through unsuitable foundation soils (e.g., peats, highly organic soils, soft fine-grained soils, loose coarse grained soils) into competent material of suitable bearing capacity; and 2. To depth where added stress due to estimated footing load is less than 10% of the existing effective soil overburden stress; or 3. Min. of 3 m (10 ft) into bedrock if bedrock is encountered at shallower depth as determined by 2.
Retaining Walls	Min. 1 boring per wall. Additional borings spaced 15 to 60 m (50 to 200 ft). Some borings should be in front of and in back of wall.	Continue borings to depth of 2 times wall height or minimum of 3 m (10 ft) into bedrock.
Bridge Approach Embankments Over Soft Ground	When approach embankments are placed over soft ground at least 1 boring should be made at each embankment to determine the problems associated with stability and settlement of the embankment. Test borings at proposed abutment locations may serve both stability and structural investigations.	Same as established above for structure foundations: Additional shallow explorations (hand auger holes) taken at approach embankment locations are an economical way to determine depth of unsuitable surface soils or topsoil.
Cuts and Embankments	Space borings every 60 m (200 ft) (erratic conditions) to 150 m (500 ft) (uniform conditions) with at least 1 boring taken in each separate land form. For high cuts and fills (8 m (26 ft) or greater), it is desirable to have a min. of 2 borings along a straight line to establish geological cross section for analysis.	**Cuts** 1. In stable materials extend borings min. 3 m (10 ft) below proposed centerline grade. 2. In weak soils, at or near proposed centerline grade, extend borings below grade to competent materials. **Embankments** Continue borings to competent material or to depth of 2 times the embankment height.
Landslides	Min. 2 borings along a straight line to establish geologic cross section for analysis. Number of sections depends on extend of stability problem. For an active slide, place at least 1 boring above and below sliding area.	Extend borings to an elevation below active or potential failure surface and into competent stratum, or to a depth for which failure is unlikely because of geometry of cross section. Bore holes used to install inclinometers must be extended to competent material below the slide movement.
Material Sites (Borrow Sources and Quarries) .	Space borings or test pits on a grid pattern every 30 to 45 m or change of material.	Extend exploration to base of deposit or to depth required to provide needed quantity.
Pavement Rehabilitation	Min. 1 boring or test pit/km (mi) with additional exploration as needed to define changes in subgrade material, pavement section and locally distressed areas.	Extend depth to at least 0.6 m (2 ft) below expected subgrade.

Exhibit 6.3-E GUIDELINES FOR GEOTECHNICAL DRILLINING INVESTIGATIONS*

**Information obtained from drilling may be supplemented by geophysical investigations.*

6.3.3 Drilling and Sampling

The purpose of a drilling and sampling program is to obtain samples that reasonably represent subsurface conditions over the entire project site. Guidance for selection of the applicable boring test type can be found in Exhibit 6.3-F.

Sampling type and frequency is dependent upon both the type of material encountered and the purpose of the investigation. The AASHTO *Manual on Subsurface Investigation* provides additional detailed information. When appropriate, continuous sampling provides the most complete and accurate information. When equipment, materials or cost effectiveness prevent continuous sampling, typical sampling frequencies used are provided in Exhibit 6.3-G. The preliminary boring plan is documented and transmitted to the field crews by use of Form 6.3-B. Exhibits 6.3-H, 6.3-I, 6.3-J and 6.3-K are used to document the materials encountered in the borings.

Boring Method	Procedure Utilized	Applicability	Typical uses
Auger Boring (AASHTO T 203)	Hand or power operated augering with periodic removal of material. In some cases, continuous auger may be used requiring only one withdrawal. Changes indicated by examination of material removed.	Probe investigations to bedrock and shallow disturbed soil samples (less than 6 m (20 ft) in depth).	Disturbed soil sampling. Determine depth of overburden.
Hollow-stem Auger (AASHTO T 251)	Power operated, hollow stem serves as a casing.	General purpose for soils and other locations requiring a cased hole.	Disturbed and undisturbed soil sampling and in-situ testing. Foundation and landslide investigations.
Rotary Drilling (AASHTO T 225)	Power rotation of drilling bit as circulating fluid removes cutting from hole. Changes indicated by rate of progress, action of drilling tools and examination of cuttings in drilling fluid. Casing usually not required except near surface.	A method to advance borings through a variety of materials including large boulders and broken rock.	Obtaining rock cores, drilling probes, horizontal drains and installing instruments.
Wire-line Drilling	Rotary type drilling method where the coring device is an integral part of the drill rod string which also serves as a casing. Core samples obtained by removing inner barrel assembly from the core barrel portion of the drill rod. The inner barrel is released by a retriever lowered by a wire-length through drilling rod.	Efficient method of recovering core samples of rock.	Foundations, material sources and rock cut investigation. General rock coring.

Exhibit 6.3-F TEST BORINGS — TYPES AND APPLICATION

Sand-Gravel Soils
SPT[1] (split-spoon) samples should be taken at 1.5 m (5 ft) intervals and at significant changes in soil strata. Continuous SPT samples are recommended in the top 4.5 m (15 ft) of borings made at locations where spread footings may be placed in natural soils. Representative SPT jar or bag samples should be laboratory classified for verification of field visual soil identification.
Silt-Clay Soils
SPT and "undisturbed" thin wall tube samples[2] should be taken at 1.5 m (5 ft) intervals and at significant changes in strata. SPT and tube samples may be alternated in same boring or tube samples may be taken in separate undisturbed boring. Representative SPT jar or bag samples should be laboratory classified for verification of field visual soil identification. Tube samples should be tested for consolidation (for settlement analysis) and strength (for slope stability and foundation bearing capacity analysis), Field vane shear testing also recommended to obtain in-place shear strength of soft clays, silts and nonfibrous peats.
Rock
Continuous cores should be obtained in rock or shales using double or triple tube core barrels. For foundation investigations, core a minimum of 3 m (10 ft) into the rock. Core samples should be evaluated for strength testing (unconfined compression) for foundation investigations and valued for quality tests for quarry investigations (aggregate or riprap). Determine percent core recovery and RQD[3] value for each core run and record in the bore log.
Groundwater
Record water level encountered during drilling, at completion of boring, and at 24 hours after completion of boring in the bore log. When water is used for drilling fluid, adequate time should be permitted after hole completion for the water level to stabilize (more than one week may be required). In impermeable soils, a plastic pipe water observation well should be installed to allow monitoring of the water level over a period of time. Artesian pressure and seepage zones, if encountered, should also be noted in the bore log. The top 300 mm (1 ft) or so for the annular space between water observation well pipes and the borehole wall should be backfilled with grout, bentonite or a sand-cement mixture to prevent surface water inflow which can cause erroneous groundwater level readings.

Notes:

1. *Standard Penetration Test, AASHTO T 206-87(2000)*
2. *Thin-Walled Tube Sampling of Soils, AASHTO T 207-96(2000)*
3. *Rock Quality Designation*

Exhibit 6.3-G SAMPLING GUIDELINES

Preliminary Boring and Testing Plan

Project ______________________________

Account Number: ______________________________

Driller: ____________________ **Engr/Geol:** ____________________

Location (station/offset)	Power Auger			Backhoe Depth	Hand Auger Depth	Pene-trometer Cone Depth	Seismic Line Length	Resistivity Maximum Spacing	Other Tests or Remarks
	Depth	SPT	Shelby Tube						

Form 6.3-B PRELIMINARY BORING AND TESTING PLAN

Sample Boring Log

Project Name:	Boring No.	Date	Sheet of
Boring Location:	Type of Boring		
Drill: Driller:	Casing Used	Size	
Field Logged By:	Boring Began:	Completed:	
Revisions/Final By:	Ground Elev.	Weather:	

Run or Sample Number	Depth From: To: Meters (feet)	Core Length Recovered / % Recovered	RQD / Fracture Spacing	SPT Blows per 150 mm (6 in)	Lab Test / Adjusted SPT (N′) per 0.3 m (1 ft)	Water Depth: / Date/Time / Description: (Density, Color, Type, Moisture, Other)

Form 6.3-C BORING LOG

Sample Boring Log

Project Name: WA FH101 Cascade Rd.		Boring No. 1	Date: 1/12/95	Sheet 1 of 1
Boring Location: 30m Lt: of P-103 stake		Type of Boring Auger		
Drill: CME 75	Driller: P. Sloan	Casing Used N/A	Size	
Field Logged By: P. Sloan		Boring Began: 1/12/95		Completed: 1/12/95
Revisions/Final By: D. Lofgren		Ground Elev.	Weather: Fair/Cold	

Water Depth:	5.8 m (19 ft)	5.8 m (19 ft)	6.4 m (21 ft)
Date/Time	4 P.M. 1 /12	7 A.M. 1/13	7 A.M. 1/17

Run or Sample Number	Depth From: To: Meters (feet)	Core Length Recovered / % Recovered	RQD / Fracture Spacing	SPT Blows per 150 mm (6 in)	Lab Test / Adjusted SPT (N') per 0.3 m (1 ft)	Description: (Density, Color, Type, Moisture, Other)
1	0 / 0.8 (2.6)	– / –	— / —		—	
2	0.8 (2.6) / 1.2 (4)	0.4 / —	— / —	3 6 8	—	
3	1.2 (4) / 2.3 (7.5)	– / –	— / —		—	
4	2.3 (7.5) / 2.7 (9)	0.1 / —	—	12 50+	—	
5	2.7 (9) / 4.6 (15)	1.2 / 63	0 / 10-50		—	
6	4.6 (15) / 6.1 (20)	1.4 / 93	15 / 50-150		—	
7	6.1 (20) / 7.6 (25)	1.5 / 100	75 / 75-200		—	
8	7.6 (25) / 10.0 (33)	2.4 / 100	90 / 200+		—	

Exhibit 6.3-H SAMPLE BORING LOG

Soil Color	Color Code
Brown	BR
Lt. Brown	LT BR
Dk. Brown	DK BR
Grey	GREY
Lt. Grey	LT GR
Dk. Grey	DK GR
Red	RED
Black	BLK
Blue	BLUE
Grey-Brown	GR BR
Grey-Red	GR RD
Brown-Red	BR RD
Yellow	YELL
Purple	PURP
Green	GREEN
White	WHITE
Grey-Green	GR GN
Mottled	MOTT
Orange	ORAN

*See Exhibit 6.3-K - Field Classification for Soil and Rock.

Exhibit 6.3-I BORING LOG TERMINOLOGY
(Soil Color)

Soil Description[1]	**Terms**
Soil Density, Consistency or Hardness	See Exhibit 6.3-M
Color	See Exhibit 6.3-K
Major Grain Size	The grain size that is > 50% of sample
Modifying Term	AND – 40% to 50% of minor grain size SOME – 10% to 40% of minor grain size TRACE – Less than 10% of minor grain size
Minor Grain Size	The next visible grain size.
Moisture Content	D – DRY M – MOIST W - WET
Laboratory Classification (i.e., AASHOT, Unified)	

Notes:

1. The following provides an example of soil description:

Medium dense, reddish brown, silt, SOME fine sand, TRACE of Clay (MOIST), A-4.

Exhibit 6.3-J BORING LOG TERMINOLOGY (Soil Description)

Particle Size Limits of Soil Constituents[1]		Cohesive Soils			Granular Soils		Rock Hardness[4]		Rock Quality [3]	
	Sieve Size	Consistency	Field Identification	Resistance[3] By SPT	Relative Density	Resistance[3] By SPT	Hardness	Field Identification	Structural Quality	RQD[5]
Boulder (BLDR)	305 mm +	**Very Soft (SI)**	Easily penetrated 100 to 150 mm by fist	0-1	**Very Loose**	0-4	**Very Soft (R1)**	Crumbles under firm blows with point of geological pick. Can be peeled by a pocket knife.	**Very Poor**	0-25%
Cobble (COBB)	75-305 mm	**Soft (S2)**	Easily penetrated 50 to 75 mm by thumb	2-4	**Loose**	5-10	**Soft (R2)**	Can be peeled by a pocketknife with difficulty, shallow indentations made by firm blow of geological pick.	**Poor**	25-50%
Gravel (GR)	2-75 mm	**Firm (S3)**	Can be penetrated 50 to 75 mm by thumb with moderate effort	5-8	**Medium Dense**	11-24	**Medium Hard (R3)**	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of hammer end of geological pick.	**Fair**	50-75%
Sand (SA)	0.075-2 mm	**Stiff (S4)**	Readily indented by thumb but penetrated only with great effort	9-15	**Dense**	25-50	**Hard (R4)**	Specimen required more than one blow with hammer end of geological pick to fracture it.	**Good**	75-90%
Silt (SI)	Smaller than 0.075 mm (nonplastic)	**Very Stiff (S5)**	Readily indented by thumbnail	16-30	**Very Dense**	50 +	**Very Hard (R5)**	Specimen required many blows of hammer end of geological pick to fracture it.	**Excellent**	90-100%
Clay (CL)	Smaller than 0.075 mm (plastic)	**Hard (S6)**	Indented with difficulty by thumbnail	31 +			**Extremely Hard (R6)**	Specimen can only be chipped with geological pick		

Notes:
[1]ASTM D653
[2]ASTM D2113
[3]Standard penetration test, AASHTO T-206-87(2000), No. of blows 0.3 m, N corrected for overburden pressure (N')
[4]Douglass Piteau, 1977
[5]Rock quality designation, percent of core run 100 mm or greater in length.

Exhibit 6.3-K FIELD CLASSIFICATIONS FOR SOIL AND ROCK
(Metric)

To Be Provided

Exhibit 6.3-K FIELD CLASSIFICATIONS FOR SOIL AND ROCK
(US Customary)

Soil samples and rock cores obtained represent a considerable investment of time and money. The samples should be properly labeled, transported and stored. A detailed treatment of procedures for handling and storing samples is provided in the AASHTO *Manual on Subsurface Investigations*. However, any method that satisfactorily protects a sample from shock, large temperature changes and moisture loss may be used. All containers used for storage should be identified with the following:

- project name and number,
- box number of total set,
- bore hole number, and
- applicable depth information.

The identification markings should be on the exterior as well as the interior of the storage container. Rock cores should be routinely photographed in color as soon as possible after being taken from the bore hole and before laboratory testing. All samples not used in laboratory testing should be retained until the proposed construction is completed and/or all claims are settled.

6.3.4 Geophysical and In-Situ Tests

Geophysical methods are used to gather information on the geological surface features. Generally, geophysical methods are used as a reconnaissance investigation to cover large areas and/or to supplement information between bore holes. The methods given in Exhibit 6.3-L should be considered to determine when geophysical testing may provide an economical means of obtaining information. Many benefits may be obtained by the use of geophysical tests, but specific procedures and limitations of the testing methods should always be considered. Additional information regarding geophysical investigations is contained in *Physical Principles of Exploration Methods*.

Seismic refraction geophysical tests are used to provide preliminary subsurface information for the items below:

- planning detailed drilling investigations,
- writing project feasibility studies,
- engineering studies,
- estimating rippability of rock excavation (see Exhibit 6.3-M) and
- extending data between bore holes.

Exhibit 6.3-N is a form commonly used to collect field seismic information. Detailed procedures can be found in Bison's *Handbook of Engineering Geophysics*, Volume I. Seismic refraction can only be used to provide reliable information when subsurface strata become more dense with depth. When the subsurface strata are expected to violate this situation, electrical resistivity has provided good results on specific projects. Resistivity is somewhat more difficult to interpret but should be routinely considered. Exhibit 6.3-O may be used to collect field data. Detailed analysis procedures and other resistivity information can be found in Bison's *Handbook of Engineering, Geophysics*, Volume II.

Method	Basic Properties and Measurements	Applications	Frequency of Use
Electrical Resistivity	Electrical conductivity of subsurface materials as measured by apparent resistance.	Identify layers of less competent material laying below more competent layers. Interpolate surface condition between bore holes	Common
Induced Polarization	Electrochemical properties or rock particles and ion concentrations in pore fluids measured by polarization voltages.	Identify location and concentration of potentially environmentally harmful rock material (primarily iron sulfides).	Rare
Seismic Refraction	Density and elasticity of subsurface material as measured by velocities of compression waves.	Estimate depth of more competent materials underlaying less competent material. Interpolate subsurface condition between bore holes.	Common

Exhibit 6.3-L GUIDELINES FOR USING GEOPHYSICAL METHODS

The most commonly used in-situ test for surface investigations is the Standard Penetration Test (SPT), AASHTO T 206-87(2000). Some common problems or procedural errors that can provide misleading results are given in Exhibit 6.3-P. The use of automatic hammers for SPT is recommended if standard drop height and hammer weight can be maintained. SPT values obtained with automatic hammers should be calibrated by field comparisons with standard drop hammer methods. All SPT values should be corrected for overburden pressure. The Bazaraa Method as given in the FHWA publication *Soils and Foundation Workshop Manual* should be used for FLH projects. Exhibit 6.3-Q provides empirical soil parameters from corrected SPT values for granular soils.

Another commonly used in-situ test is the Cone Penetrometer Test (CPT). This test can provide in-situ soil strength parameters and a differentiation between end bearing and side friction for pile design. The test can provide accurate and economical test results in soft to medium dense sands, silts and clays. Major drawbacks of CPT are that samples are not recoverable and that tests in dense and/or gravel deposits are difficult and may damage equipment. FHWA-SA-91-043 Manual entitled *The Cone Penetrometer Test* should be reviewed before field CPT is attempted. Exhibit 6.3-R is an example presentation of field CPT data.

Other commonly used in-situ devices are vane shear tests and pressuremeter tests. *Geotechnical Engineering Investigation Manual* and AASHTO *Manual on Subsurface Investigations* provide additional details on these devices.

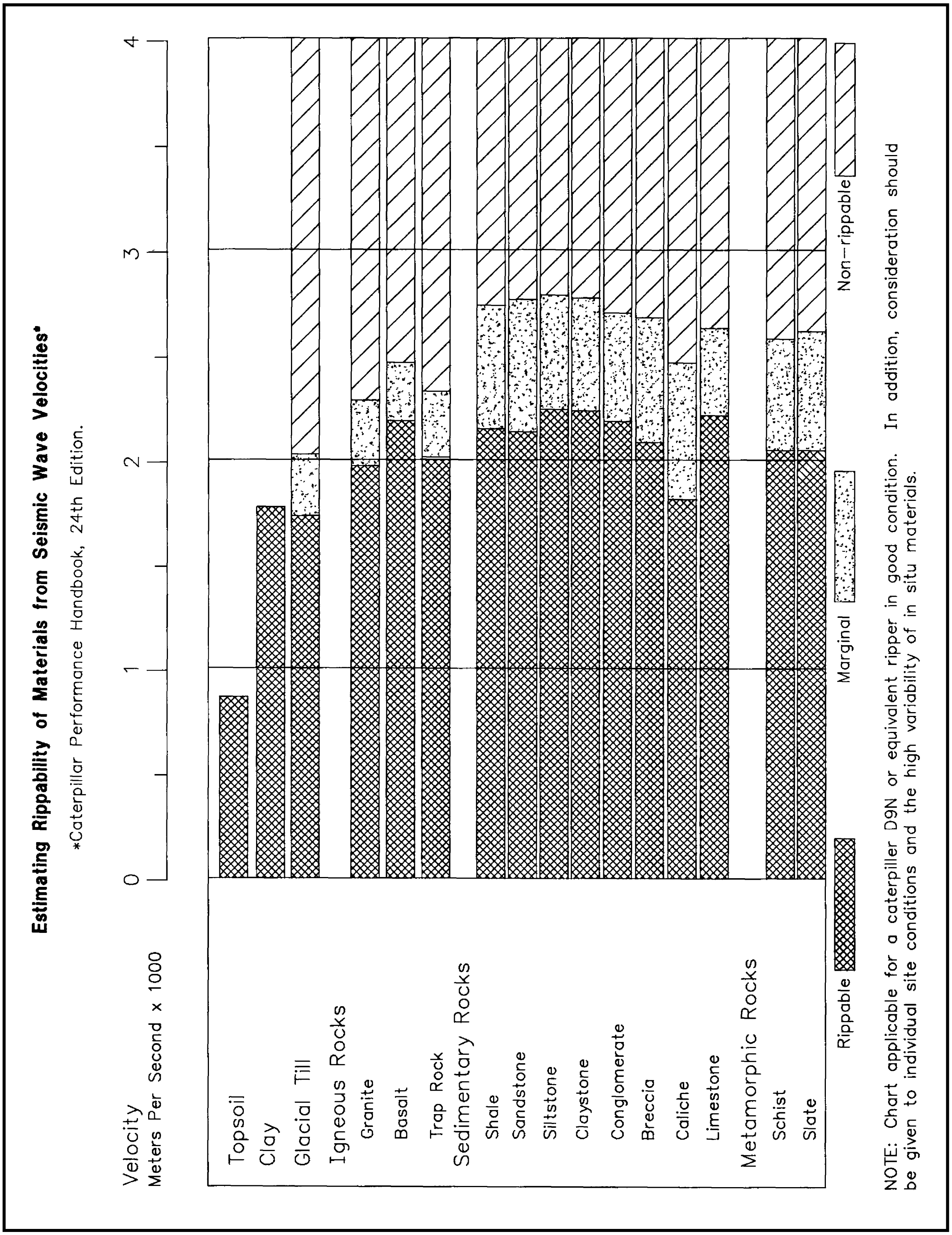


Exhibit 6.3-M ESTIMATING RIPPABILLITY OF MATERIALS FROM SEISMIC WAVE VELOCITIES*
(Metric)

To Be Provided

Exhibit 6.3-M ESTIMATING RIPPABILLITY OF MATERIALS FROM SEISMIC WAVE VELOCITIES*
(US Customary)

Seismograph Data Sheet		
Project Name:	Operator:	Date :
Location Description :		
Field Notes :		

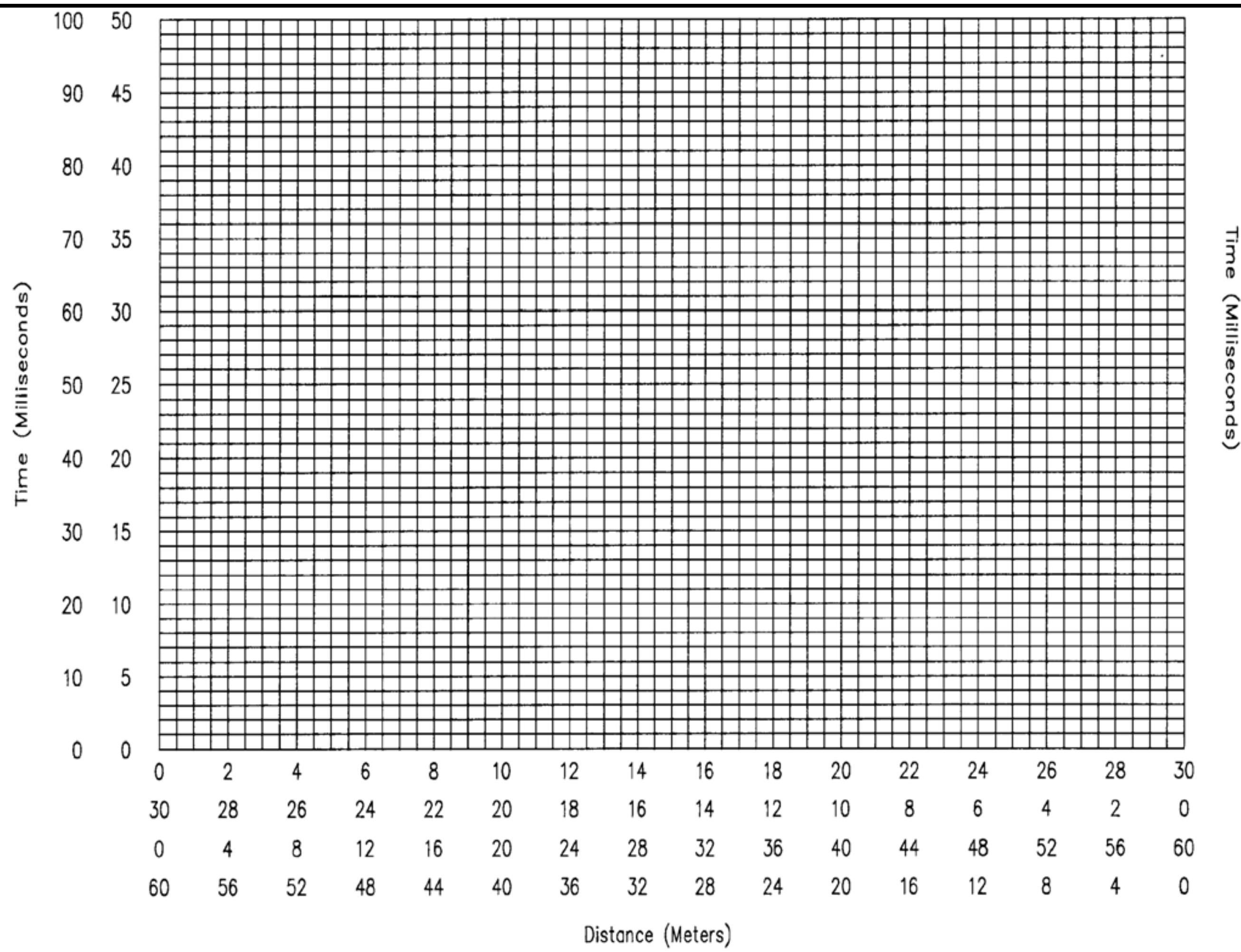


Exhibit 6.3-N SEISMOGRAPH DATA SHEET

To Be Provided

Exhibit 6.3-N SEISMOGRAPH DATA SHEET
(US Customary)

Resistivity Data Sheet

Project Name: ______________________________ **Date:** ______________________________

Location Description: ________________________ Operator: ______________________________

Notes: ____

____

____

Apparent Resistivity = (Electrode Spacing) (Dial Reading) (Scale Factor)

No.	Electrode Spacing m (ft)	Dial Reading	Scale Factor	Apparent Resistivity (Ω · m) (Ω · ft)	Cumulative Resistivity (Ω · m) (Ω · ft)

Exhibit 6.3-O RESISTIVITY DATA SHEET

Resistivity Data Sheet (continued)

Project Name: ______________________________ *Test No.:* ______________

Test Location: Test Date:

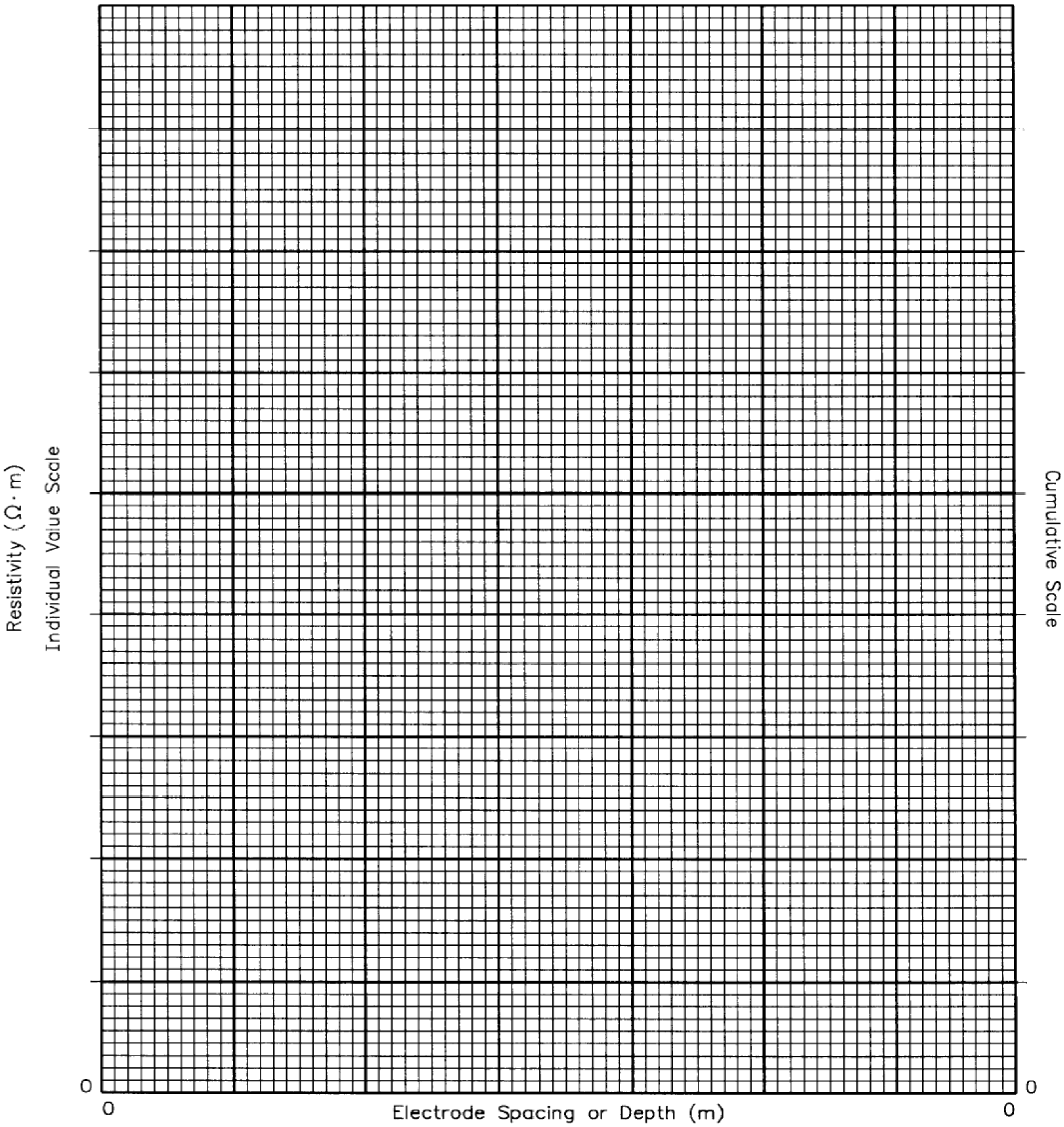


Exhibit 6.3-O RESISTIVITY DATA SHEET (Metric)
(Continued)

To Be Provided

Exhibit 6.3-O RESISTIVITY DATA SHEET (US Customary)
(Continued)

Problem	Circumstance/Cause
Inadequate cleaning and/or seating of sampler.	Sludge and debris trapped in sampler or in bottom of hole.
Failure to maintain adequate hydrostatic pressure and/or over washing ahead of casing.	Fill-up inside casing. Disturbance of in-situ material. Too large pump.
Use of damaged and/or inadequate equipment.	Tip of sampler damaged by heavy driving. Drive weight nonstandard or does not strike drive cap evenly.
Hammer does not free-fall and/or correct height of fall is not maintained.	More than 1.5 turns around cat head or wire line will restrict fall. Proper height is not maintained by operator.
Operator and/or inspector errors.	Incorrect blow count. Incorrect location and/or depth. Sampler overdriven.

Exhibit 6.3-P COMMON PROCEDURAL ERRORS USING STANDARD PENETRATION TEST

Description	Very Loose	Loose	Medium	Dense	Very Dense
Relative Density, D_r	0 0.15	0.35	0.65	0.85	1.00
Corrected Standard Penetration No. N′	4	10	30	50	
Approximate Angle of Internal Friction ϕ (2)	25-35°	27-32°	30-35°	35-40°	38-43°
Approximate Range of Moist Mass Density (p) kg/m³	1100-1600	1400-1800	1700-2100	1700-2200	2100-2400

Notes:

1. *The table provides empirical values for (ϕ), Relative density (D_R) and unit mass (y) of granular silts based on corrected N′ (Correlations may be unreliable in silts containing gravel.)*

2. *For ϕ, use larger values for granular material with 5% or less fine sand and silt.*

Exhibit 6.3-Q EMPIRICAL VALUES, RELATIVE DENSITY AND MASS DENSITY OF GRANULAR SOILS(1)
(Metric)

To Be Provided

Exhibit 6.3-Q EMPIRICAL VALUES, RELATIVE DENSITY AND MASS DENSITY OF GRANULAR SOILS*
(US Customary)

To Be Provided

Exhibit 6.3-R SAMPLE CONE PENETROMETER TEST (CPT) DATA FORM (RESERVED)

The following are types of specialized geotechnical instrumentation commonly in use:

- inclinometers,
- piezometer,
- displacement stakes,
- strain gauges, and
- earth pressure cells.

The *Geotechnical Instrumentation for Monitoring Field Performance* by Duncliff is a recommended reference for planning, designing and specifying instrumentation projects. Exhibits 6.3-S and 6.3-T are data collection sheets commonly used for field shear tests and inclinometer instrumentation.

6.3.5 Laboratory Tests

After collecting soil and rock samples, laboratory tests are routinely performed to quantify material properties and verify design assumptions. The type and number of tests required are primarily a function of the variability of the site, the purpose of the investigation and the amount of risk and potential consequences of failure. Sufficient testing should be performed so that the geotechnical project engineer or geologist is satisfied that the test results are representative of in-situ conditions.

Exhibit 6.3-U provides a guideline for estimating laboratory test requirements for the different types of analysis. Exhibit 6.3-U is representative of past experience with projects and is not intended to limit either the type of laboratory test or the frequency of testing but to provide a starting point for evaluation. See the *Geotechnical Engineering Investigation Manual* for additional information.

Requesting and transmitting samples for laboratory testing and evaluation is handled differently in each FLH Division.

Clearly identify each sample with the following:

- project,
- bore hole or test pit number and location,
- depth of sample taken, and
- specific test requested.

All detailed test results should be included in the finalized geotechnical report. Care should be taken to ensure that only factual data is presented or that all interpretations of laboratory data are clearly identified as such.

Bore Hole Shear Test

Project: ____________________ Boring No: ______________ Test No: ________

Location: ______________________________ Date: ____________________

Depth: ______________________________ Tested By: ____________________

Description: ____

Point No.	Normal Stress		Shear Stress		Time*	Remarks
	Gage	σ_n	Gage	τ_{max}		

*Consolidation time

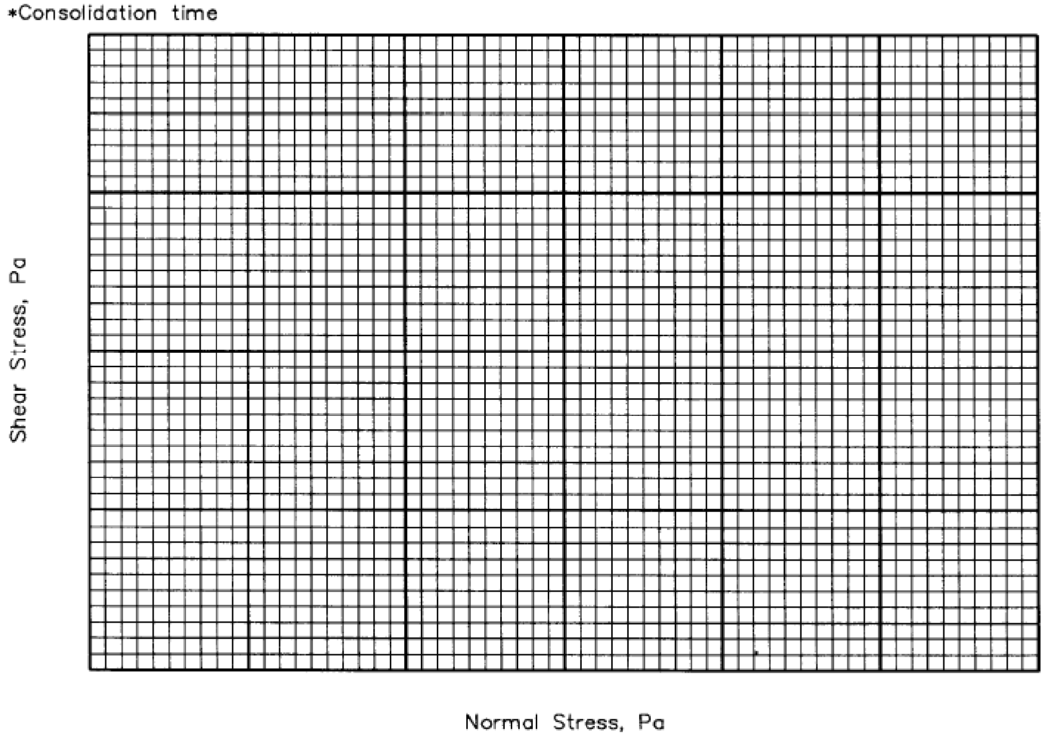


Exhibit 6.3-S BORE HOLE SHEAR TEST

Inclinometer Data

Well No. ____________________________

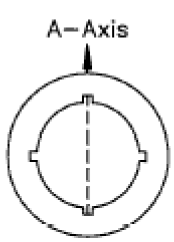
Reading No. __________________________

Project: ____

Location: ____

Date: ____________________ Readings taken by: ____

Depth	A_z=A			A_z=B		
	#1	#2		#1	#2	
1 4	8 13	17 22		26 31	35 40	
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						
0						



A–Axis Bearing = ________________
of casing

Water Depth: ___________________

Note: All numerical data must be right justified.

Elevation

________________________ Top

Top reading _____________

Bottom reading __________

Exhibit 6.3-T INCLINOMETER DATA

Test Analysis Type	Laboratory Tests Selection Frequency									
	A	B	C	D	E	F	G	H	I	J
Roadway Soil	F	F	F	L	F	F	L	M	L	L
Structural Foundation	F	M	F	L	L	R	F	M	F-M	M
Retaining Wall	F	M	F	M	L	R	F-M	F-M	F-M	M
Pavement Design	F	F	F	M	F	F	L	L	L	L
Material Source	F	F	F	R	F	F	R	M-L	L	L
Landslides	F	F	F	F	L	R	F-M	F-M	F	M

Test Description:

A — Gradation (Classification) AASHTO T88, T89, T90, T100
B — Fine Grain Analysis AASHTO T88
C — Atterberg Limits AASHTO T89, T90
D — Permeability Tests AASHTO T215
E — Remolded Density AASHTO T180 or T99
F — R-Value/CBR/M AASHTO T190, T193, T292, T294 $_r$
G — Unconfined Compression AASHTO T 208
H — Direct Shear AASHTO T 236
I — Triaxial AASHTO T296, T297
J — Consolidation AASHTO T216

Selection Legend:

F — Frequent/Routine Use
M — Moderate Use
L — Limited Use
R — Rarely Used

Exhibit 6.3-U GUIDELINES FOR SELECTION OF LABORATORY TESTS